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DEVELOPMENT OF EXPOSURE GUIDANCE FOR WARM WATER DIVING:

Volume 2 — System for Investigation of Divers' Behavior at Depth (SINDBAD)

and

Special Operations Forces (SOF) Mission-Related Performance Measures (MRPM)

NAVSEA
NAVAL SEA SYSTEMS COMMAND
Navy Experimental Diving Unit

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19. ABSTRACT (Continue on reverse if necessary and identify by block number). Objective: To provide guidance for conducting diving operations in warm water environments. This report, Volume 2 of two, investigates the effects of warm water diving on physical and cognitive performance. Method: This study was conducted in three phases. In Phase 1, 16 divers conducted 458 dives T_w from 94 to 101.5 °F (34.4 to 38.6 °C). In Phase 2, 21 divers in either dry suits or "dive skins," conducted 522 dives in T_w of 96.5 °F (35.8 °C) and 99 °F (37.2 °C), respectively. In Phase 3, 24 divers in different forms of USN diving dress completed 784 dives in T_w between 90 and 101.5 °F (32.2 and 38.6 °C). Cognitive and physical testing was conducted with subtests from the System for Investigation of Divers' Behavior at Depth (SINDBAD) and the Special Operations Forces Mission Related Performance Measures (SOF MRPM). The physiological performance is discussed in Volume 1 of this report. Results: Neither the SINDBAD nor the SOF MRPM subtests provided evidence of a T_w effect on cognitive performance. Because of marked changes in diver endurance and other physiological measures (see Volume 1 of this report), results were expected to show significant degradations as T_w and degrees of thermal protection (resulting from diver dress) increased. Conclusions: Although divers immersed in warm water can be hot and uncomfortable, as long as their core temperatures are kept below a maximum of 102 °F (38.9 °C), the effects of T_w on cognitive performance appear to be minimal. After completing a warm water dive with active cooling, rehydration, and an extended recovery period, divers recover sufficiently to minimize performance decrements.

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INTRODUCTION

GENERAL

Throughout the history of diving, operational planners have lacked guidelines for conducting operations in warm water environments. The graph on page 6-16 of the *U.S. Navy Diving Manual*[1] shows that a working diver overheats at 88 °F (31.1 °C) and a resting diver overheats at 94 °F (34.4 °C). These forecasts implicitly establish maximum temperatures for a moderately working diver and a diver at rest. Yet since operational divers are never completely at rest, this graph — although it is not normally so interpreted — could be construed as forbidding diving in water warmer than 88 °F (31.1 °C). Its guidance does imply that overheating might occur but says nothing about when that might happen, how high body temperature might be, or whether that overheating could be dangerous to the diver.

Events of the Gulf War, and contingency operations since then, have increased sustained diving operations by U.S. military units in the warm waters of the Persian Gulf. Divers there have suffered various problems attributed to high water and air temperatures,[2] problems that have affected their abilities to perform missions and have revealed needs for accurate information about the physiological effects, and limitations, that this environment imposes on missions.

Therefore, Naval Sea Systems Command (NAVSEA) tasked the Navy Experimental Diving Unit (NEDU) to conduct manned studies to develop exposure guidance for diving in warm waters.[3] The purpose was to determine the physiological and cognitive effects of water temperatures (T_w) from 94 to 101.5 °F (34.4 to 38.6 °C) on divers. Specifically, the manned diver testing was to determine the effects of

1) T_w on diver endurance;
2) T_w on diver performance (cognitive and physical);
3) T_w and diver dress on diver endurance; and
4) T_w and diver dress on diver performance (cognitive and physical).

Due to the concern for diver-subject safety under the proposed conditions, this study was conducted in phases spanning three years: Phase 1 (1999), Phase 2 (2000), and Phase 3 (2001). Phase 1 was designed to determine how warm water affected the endurance and performance of swimsuited diver-subjects in water temperatures from 94 to 101.5 °F (34.4 to 38.6 °C). One series of dives was limited to a maximum of four hours of exercise, as this approximates a combat swimmer's mission profile. The exercise rate chosen was one reasonably sustainable by combat divers: 1.5 liters/minute (L/min) of oxygen consumption ($\dot{V}O_2$).[4] A second series of dives, using swimsuited diver-subjects exposed to the same range of water temperatures but for a maximum of eight hours and resting rather than exercising, was conducted to approximate a swimmer delivery vehicle (SDV) scenario. These exercise and duration limits were also felt to cover fleet divers. During dives conducting ships husbandry and shallow water salvage diving operations, for instance, work rates might exceed 1.5

L/min $\dot{V}O_2$ for short times, but the rates should average out between these resting and continuous work levels of activity. In addition, a continuously working combat swimmer is considered to be in a worst-case situation, because his physiological and psychological condition receives no topside monitoring.

The objective of Phase 2 was to determine the effect of warm water on endurance and performance for diver-subjects wearing different forms of U.S. Navy (USN) diver dress during exercise. These dives were limited to a maximum of four hours' exercise at the same workload as that during Phase 1. Diver-subjects in either of the two forms of diving dress, dry suits and "dive skins," were tested in water temperatures of 96.5 °F (35.8 °C) and 99 °F (37.2 °C), respectively.

Phase 3 of this study was to determine the physiologic response of diver-subjects in different forms of USN diving dress at a reduced exercise rate. This phase determined whether a decreased work rate could mitigate some effects of warm water and, as a result, could increase diver endurance. Phase 3 dives were in water temperatures between 90 and 101.5 °F (32.2 and 38.6 °C). Fin-swimming versus underwater cycling was also compared.

Using the submersible System for the Investigation of Divers' Behavior at Depth (SINDBAD) and the Special Operations Forces (SOF) Mission-Related Performance Measures (MRPM), this report presents results from the investigation of cognitive effects of diving in warm water. The physiological and in-water endurance results are presented in separate report.[5]

METHODS

GENERAL

Specific testing protocols were developed for each of the three phases of this study.[6, 7, 8]

SUBJECTS

A total of 16 Navy-trained diver-subjects from NEDU and the Navy Diving and Salvage Training Center (NDSTC) were given training, including familiarization dives, with both the MK 25 underwater breathing apparatus (UBA) and the OXY-LUNG UBA (Aqua Lung America, Inc.; Vista, CA) in the NEDU test pool. These diver-subjects were then used for all subsequent testing during the particular phases of the study.

EQUIPMENT

Underwater Breathing Apparatus

Two different closed-circuit 100% O_2 rebreathers were used during this study. The USN MK 25 was used during Phase 1 resting dives at 94 °F (34.4 °C). However, after this series of dives the OXY-LUNG was used for the remainder of Phase 1 and for all diving in Phases 2 and 3. For testing purposes, this UBA was selected rather than the USN MK 25 because of cost, manufacturer technical support, and diver-subject preference.

Underwater Cycle Ergometers

Four (4) modified Collins Pedal-Mode[9] (Collins Medical; Braintree, MA), cycle ergometers were staged in the NEDU test pool. The cycle ergometer frames were set at zero inclination and were on a platform approximately three feet deep.

Exercycles (dry)

A commercial-grade Precor Model C846 (Precor USA; Woodinville, WA), recumbent exercycle was used for all dry cycle conditioning. These same cycles were used for the dry acclimation portion of Phase 2; they were believed to approximate the underwater cycle ergometers that were used for all non-finning exercise dives. As these exercycles interfaced with the Polar Accurex Plus™ heart rate monitor (Polar Electro, Inc.; Woodbury, NY), they allowed diver-subjects to monitor their heart rates during conditioning and to record those heart rates.

Test Pool and Ocean Simulation Facility (OSF)

All dives were conducted in either the NEDU test pool or the OSF, the latter of which was used only during acclimation dives because of the physical effort required to exit that facility. All testing dives were conducted in the test pool, where cycle ergometers were mounted on the three-foot-deep platform, a setup that allowed easy access to a diver-subject if either a physiological or a UBA problem occurred.

Trolling Motors

To avoid stratifying T_w and thereby to ensure a well-stirred pool temperature, two MotorGuide (Minnekota, WI) trolling motors were used to stir the water column in the test pool.

Maximum Oxygen Consumption ($\dot{V}O_2$ Max) Testing

Maximum $\dot{V}O_2$ testing was performed on all diver-subjects who participated in this study. For Phases 1 and 2 a continuous, progressive intensity treadmill test with a Collins Model Plus/GSM and Plus/CPX/M (Collins Medical, Inc.; Braintree, MA) metabolic cart was used to determine oxygen uptake and carbon dioxide ($\dot{V}CO_2$)

production. For Phase 3 a continuous, progressive intensity treadmill test with a Quinton Model Q-Stress (Quinton Cardiology Systems, Inc.; Bothell, WA) treadmill and a Collins Model Plus/CPL (Collins Medical, Inc.; Braintree, MA) metabolic cart was used.

Dry Suits

The Trelleborg Viking dry suit (Trelleborg Viking, Inc.; Portsmouth, NH), a heavy-duty vulcanized rubber suit that comprises the diving dress for the U.S. Navy's contaminated water diving system, was chosen for use during Phases 2 and 3.[10] Since protection from a contaminated environment is the only reason for wearing a dry suit in warm water, this contaminated diving dry suit was used during testing.

Dive Skins

The dive skins used for Phase 2 and Phase 3 dives are identical to those used by Navy Special Warfare (SEAL) and VSW Mine Countermeasure (MCM) divers.

Cooling Suits

During the Phase 2 proof of concept (POC) dives, a commercially available active cooling suit was used to determine whether "cooling" the diver could enhance his endurance. These suits were provided by Delta T-Max (Med-Eng System; Pembroke, Ontario).

Phase Change Material (PCM) Vests

Cool-Vest (50-Degree Company; Melbourne, FL) PCM vests are used by Explosive Ordnance Disposal (EOD) personnel, firemen, and National Aeronautical and Space Administration (NASA) rocket fuel handlers. Although different types of PCM garments are available, many are large and cumbersome, and they severely restrict diver movement. To minimize these problems, the Cool-Vest system was chosen. In addition, this vest can be "charged" via a simple ice bath and reused an unlimited number of times. During Phase 3 POC dives a commercially available passive cooling suit was used to determine whether a diver's endurance could be enhanced by cooling him and thereby preventing him from overheating.

Dry Suit Dryer

During Phase 3 a commercially available dryer was used to dry the suits so that, if needed, they could be used the following day. Using this dryer not only prevented mildew damage to the suits but also ensured that diver-subjects started their test dives with "dry" dry suits. MisoSolutions (Montrose, CO) provided the system gratis to NEDU.

INSTRUMENTATION

Rectal Temperature (T_{rec})

A YSI 700 series thermistor probe (YSI, Inc.; Yellow Springs, OH) was used to measure T_{rec} of diver-subjects during all phases of the study. This probe was inserted 15 cm past the anal verge and was retained there by a ¼-inch (6.4 mm) diameter button. This instrumentation was combined with the diver-subjects' safety umbilicals, which included a safety line, gas sampling line, and temperature probe wiring.

Pool Temperature

Another YSI 700 series thermistor probe was used to monitor the test pool temperature at the same depth as that of the diver-subjects. Pool temperature was maintained within ±0.5 °F (±0.28 °C) of the stated test temperature. To ensure a well-mixed pool temperature, trolling motors were mounted and run continuously (see **EQUIPMENT**: Trolling Motors).

Inhalation UBA Gas Temperature

A YSI 700 series thermistor probe was placed in the inhalation breathing hose to monitor inhalation gas temperatures just upstream from the one-way flapper valve in the UBA.

O_2 Bottle Pressure

Oxygen bottle pressure was continuously monitored with a Druck pressure transducer (Druck, Inc.; Braintree, MA) and was logged every 30 seconds. Oxygen consumption was calculated from changes in O_2 bottle pressure (see **METHODS**: Oxygen Consumption).

Data Recording

The following parameters were recorded with LabVIEW (National Instruments; Austin, TX) software and an NEDU data acquisition system (DAS) computer on the test pool medical deck:

1) water temperature (logged every 30 seconds);
2) zero time, actual time (logged every 30 seconds);
3) rectal temperature (T_{rec}), continuously monitored and logged every 30 seconds; and
4) inhalation UBA gas temperature (logged every 30 seconds).

Calibrations

Oxygen pressure gauges and thermistor calibrations were checked at the beginning of each day and again after the last run of the day.

Heart Rate

Heart rate was continuously monitored with Quinton Q-Tel Rehab ECG telemetry (Quinton Cardiology Systems, Inc.; Bothell, WA) and manually logged every five minutes. Additionally, diver heart rate was logged every 15 seconds with a Polar Accurex Plus™ heart rate monitor and was downloaded at the end of each diver-subject's test run.

Electrocardiograph (ECG)

ECG was observed on a monitor with Quinton Q-Tel Rehab ECG telemetry for diver-subject safety, but only heart rate from this telemetry was recorded.

O_2 and CO_2 Monitoring

During all dives using the OXY-LUNG UBA, both inspired O_2 and CO_2 concentrations were monitored for diver-subject safety. These measurements were made with an Extrel Mass Spectrometer Model GS (ABB Extrel; Pittsburgh, PA).

PHYSIOLOGICAL PARAMETERS

Urinalysis

The baseline urinalysis was made on the first morning void on the day of immersion testing. A second urine sample was required from diver-subjects before they entered the water for a test dive. This second sample was collected after they had eaten and drunk, according to the predive protocol. During test-run dives, all male diver-subjects wore external urinary catheter systems to collect urine. (Because no noninvasive urine collection system exists for females, urine was not collected from these diver-subjects during the immersion portions of this study.) Throughout the dive, this collection system was emptied as needed. Postdive urine also was collected and analyzed, but because these samples were acquired after diver-subjects had hydrated ad lib, these postdive samples were used only to fulfill postdive release criteria before the diver-subjects left NEDU. Specific urine analyses included the following:

1) Specific gravity (Phases 1, 2, and 3)
2) Myoglobin (Phase 1 only)
3) Osmolality (Phase 1 only)
4) Ketones (Phase 1 only)

Blood analysis

Baseline measurements were made on fasting blood samples drawn from diver-subjects before they ate breakfast and hydrated on the mornings of their test dives. The following hematological measurements were made predive and then repeated postdive, before diver-subjects hydrated and began postdive performance testing:

1) Hematocrit
2) Hemoglobin
3) Osmolality
4) Electrolytes (sodium, chloride, potassium, calcium, magnesium, phosphorous)
5) pH
6) Bicarbonate
7) Glucose
8) Lactate
9) BUN
10) Creatinine
11) LDH (Phase 1 only)
12) AST (Phase 1 only)
13) ALT (Phase 1 only)
14) CPK, fractionated for MM, MB, and BB isoforms when CPK was appropriately elevated (Phase 1 only)

Weight

All diver-subjects were weighed on the morning of immersion testing, after their first morning voids but before they had eaten breakfast or drunk. Before diver-subjects entered the water, they were also reweighed — a predive weight taken after they had eaten one Meals Ready to Eat (MRE), drunk 0.5 L of fluid,[11] and been instrumented for their dives. All diver-subjects were also weighed immediately postdive.

Diver-Subject Vital Signs

All diver-subjects had blood pressures and pulse rates taken while they were seated and then one minute after standing during the morning predive weigh-in and blood draw. These measurements were also performed as soon as the divers exited the water postdive.

Visual Acuity

During Phase 1 testing, a Snellen Chart was used to measure the visual acuity of the diver-subject at 20 feet. Visual acuity was measured both pre- and postdive because of concern for hyperoxic myopia. This testing was discontinued for Phases 2 and 3, because no effect was seen during Phase 1 testing.

Daily Diver Routine

All diver-subjects were required to follow the standard predive routine outlined in Appendix A and provided to diver-subjects the afternoon before their scheduled dives.

DIVER-SUBJECT SYMPTOMS

During Phase 1 dives at water temperatures of 78, 94, and 96.5 °F (25.6, 34.4, and 35.8 °C), diver-subjects were asked a series of questions (see Appendix C) approximately every 60 minutes. This interval was shortened to approximately every 30 minutes during all dives at 94 and 96.5 °F (34.4 and 35.8 °C). During Phases 2 and 3 this same questionnaire was used, with questions again asked every 60 minutes, or every 30 minutes for short-duration dives. This questionnaire afforded a subjective evaluation of the diver-subjects' symptoms associated with O_2 toxicity and heat stress; its results were recorded manually on a data collection sheet and later manually entered into a database.

OXYGEN CONSUMPTION

Maximum Oxygen Consumption

All diver-subjects completed a progressive intensity $\dot{V}O_2$ max test [see **EQUIPMENT**: Maximum Oxygen Consumption ($\dot{V}O_2$ Max) Testing] before they started test dives. The only exception to this procedure occurred during Phase 3, when this testing was done late in the diving phase because of equipment problems. For Phase 3 the diver-subjects' most recent USN Physical Readiness Test (PRT) results were used to divide the diver-subject pool into two balanced groups, with groupings based on sorted results from the PRT. These two groups were then used as diver-subjects for heat acclimation studies. Use of these PRT results was necessary because of equipment problems associated with $\dot{V}O_2$ max testing.

Oxygen Consumption ($\dot{V}O_2$)

The diver-subjects' in-water oxygen consumption during acclimation, resting, and exercise dives was calculated from recorded UBA O_2 bottle pressure changes during the dive. This delta P was then used to calculate oxygen consumption per the following equation:

$$\dot{V}O_2 = [(P_{START} - P_{FINISH}) / t] \times [V_b / 14.7 \text{ psig}] \times 273 / (T + 273),$$

where

$\dot{V}O_2$ = oxygen consumption (L/min, standard temperature pressure dry [STPD]),
P_{START} = O_2 bottle starting pressure (psig),
P_{FINISH} = O_2 bottle finish pressure (psig),

t = time interval (min) for which $\dot{V}O_2$ is being calculated,
V_b = floodable volume of O_2 bottle in liters (L), and
T = temperature (°C).

CONDITIONING

Cycling

All diver-subjects underwent predive exercise conditioning by riding a stationary exercycle. During Phase 1 these cycles were placed in the NEDU environmental chamber (EC), where temperature was 94 °F (34.4 °C) and relative humidity was 50%. During cycling conditioning, all diver-subjects were provided their own personal hydration systems to ensure adequate hydration during those extended cycle training periods. The tapered increase in required cycling was the same for all three phases (see Appendix D). During subsequent phases, cycle conditioning was conducted in the NEDU physiology lab, an air-conditioned facility with an average ambient temperature of 78 °F (25.6 °C). This conditioning temperature was used because two different heat acclimation strategies were employed during Phases 2 and 3 [see **CONDITIONING**: Heat Conditioning (Acclimation)].

Fin Conditioning

Fin conditioning was scheduled three times per week, but diver-subjects were required to participate in only two of the three sessions. These sessions were arranged to accommodate NEDU work schedules and to allow diver-subjects to continue to fin swim even after the start of underwater cycle ergometer testing. Fin conditioning entailed finning sessions of increasing duration in St. Andrew Bay, Panama City, FL, at ambient water temperature. Diver-subjects used dive fins of their choice for the first three weeks, but then were provided with either Apollo Bio-Fins (Apollo Sports USA, Inc.; Everett, WA) or ScubaPro TwinJet (ScubaPro/Uwatec; El Cajon, CA) fins for these sessions. Diver-subjects were instructed not to use their arms during these sessions. To maintain the achieved level of conditioning, diver-subjects continued this fin conditioning through the cycling portion of the protocol.

Heat Conditioning (Acclimation)

Heat acclimation for diver-subjects was conducted in two different ways. The first was natural heat acclimation, which occurs with diver-subjects doing nothing and was the main reason that study dates were set to be as similar as possible during the different years. Panama City, FL, is located on the Gulf of Mexico and has an average summertime temperature of 76.8 °F (24.9 °C) from May through October.[12] The average high temperature for these months is 86.6 °F (30.3 °C), and the average low, 71.2 °F (21.8 °C). Because NEDU has mandatory outdoor physical training three days a week from 0700 until 0830 hours, all diver-subjects were exposed to natural heat acclimation from living, working, and exercising in Panama City.

However, to ensure that all diver-subjects were heat acclimated at the beginning of testing, a second means of heat acclimation was required of them. As described for each phase in the immediately ensuing paragraphs, this acclimation consisted of being exposed to a hot environment, either wet or dry. Selection of these heat acclimation strategies was based on concurrent research at NEDU to determine optimum the acclimating strategy,[13] and the results are not presented here. It is generally agreed that most acclimation to heat occurs within the first seven days' exposure; there is no sharp end to improvement.[14] Consequently, regardless of the second heat acclimation strategy used, ten days of heat exposure was felt to be sufficient to acclimate all diver-subjects.[13] To ensure that natural acclimation was as consistent as possible, Phases 1, 2, and 3 were all conducted during the months from May through October 1999, 2000, and 2001, respectively.

All Phase 1 cycle conditioning was performed at constant conditions in the NEDU environmental chamber (see **CONDITIONING**: Cycling).

During Phase 2, two different heat acclimation strategies were used. Following $\dot{V}O_2$ max testing, diver-subjects were sorted by $\dot{V}O_2$ max scores and evenly divided into two groups for heat acclimation. This sorting was to ensure that each heat acclimation group was representative of the entire diver-subject pool for a particular phase. Then, for two weeks,

1) 50% of the diver-subjects exercised on underwater cycle ergometers at 50 watts for one hour in 94 °F (34.4 °C) water, and

2) 50% of the diver-subjects exercised on the recumbent exercycles at 125–150 watts for one hour in the environmental chamber (where they were dry) at 94 °F (34.4 °C) and 50% relative humidity.

During Phase 3 all heat acclimation was conducted on underwater cycle ergometers. Due to equipment problems with the $\dot{V}O_2$ max testing equipment, diver-subjects were sorted by their last USN PRT scores and then evenly divided into one of two groups for heat acclimation. This sorting ensured that each heat acclimation group was representative of the entire diver-subject pool for a particular phase. Then, for two weeks,

1) 50% of the diver-subjects exercised at 50 watts for two hours in 94 °F (34.4 °C) water, and

2) 50% of the diver-subjects exercised at 0 watts for one hour in 98 °F (36.7 °C) water.

Because of difficulties with the computer that set the workload for the cycle ergometers, the 98 °F (36.7 °C) group performed at a workload (watts) different from that of the 94 °F (34.4 °C) group.

COGNITIVE AND PHYSICAL PERFORMANCE MEASURES

SINDBAD In-Water Testing

In-water testing was conducted with the SINDBAD,[15] which consists of a computer and a submersible response panel.

The SINDBAD system was used during this study to assess changes in diver performance during water dives. The assessment was conducted at repeated intervals from the time the diver entered the water until the dive was terminated. While the SINDBAD system consists of 30 different tests of perceptual, memory, cognitive, and psychomotor abilities, only five tests designed for in-water testing were used during this study.

Key-Insertion Test — This test was designed to measure fine motor coordination. Using only the preferred hand, the diver inserted alternately the round and the square ends of a 1-inch key device into a round and a square cell on the display-response panel. The test lasted for 60 seconds. The score represents the number of responses completed minus the number of failures to alternate.

Stylus Test — This test measured tapping coordination. The diver inserted the stylus into a display-response panel cell as many times as possible during a 30-second test. The score represents the number of responses completed minus the number of irrelevant responses.

Visual Reaction Time Test — This test measured reaction speed to a simple, discrete stimulus. The diver had to remove the stylus from the asterisk cell as rapidly as possible when the numeric group at the top of the panel was illuminated with all zeroes. In each of 20 trials, a delay of from one to three seconds was inserted between the diver's ready response (inserting the stylus into the asterisk cell) and the onset of the stimulus, with delays being randomly ordered over trials. The score is the mean reaction time in seconds.

Visual Digit Span Test — This test measured span memory, the ability to reproduce material very recently studied. The diver had to reproduce accurately a numeral series immediately after the series was presented. At a rate of one per second, numerals in the series were presented on a numeric display at the top of the display-response panel. The score is number of correct responses.

Operation Test — This test measured general reasoning and numerical ability. The diver was given two numerals and a solution; the task was to select one of the simple arithmetic operations (addition, subtraction, multiplication, or division) that would produce the solution for the numerals. Instructions emphasized speed to discourage

actual computation. Test time was two minutes. The score is the number of correct responses minus the number of incorrect responses divided by three.

For Phase 1, to avoid having a training effect on the diver-subjects during data collection runs, training with the SINDBAD was conducted in a dry environment. Wet training with SINDBAD and reaction time testing with a mask and snorkel in a hot tub at 78 °F (25.6 °C) also was conducted for in-water baseline proficiency and familiarization. Training was conducted until diver-subjects reached ±5% baseline stability for the SINDBAD in a dry environment. During this phase the first SINDBAD test of each day also was done predive (dry).

During Phases 2 and 3 all training and testing was conducted while diver-subjects were submerged. During acclimation and familiarization dives no testing was done, although diver-subjects practiced with the SINDBAD. The schedule for SINDBAD testing in each phase was performed as follows:

Phase 1	pre- and postdive (dry = air), and either every 30 minutes (exercise) or every hour (rest) during in-water periods;
Phases 2 and 3	only in the water and every hour or at 30-minute intervals, with diver endurance (based on Phase 1 testing results) expected to be less than two hours.

During Phases 2 and 3, in-water SINDBAD testing occurred immediately after the diver-subject was settled in the water, and then every 60 minutes until dive termination. During Phase 1 dives at water temperatures of 78, 94, and 96.5 °F (25.6, 34.4, and 35.8 °C), SINDBAD testing was conducted every 60 minutes. However, this interval was shortened to approximately every 30 minutes during Phase 1 dives with temperatures greater than 96.5 °F (35.8 °C). The testing interval was also shortened to 30 minutes during Phase 2 and 3 dives, when diver endurance was expected to be less than two hours.

Special Operations Forces (SOF) Mission-Related Performance Measures (MRPM)

This performance battery was used to assess a diver-subject's ability to perform mission-related tasks following a warm water dive exposure. All MRPM testing was postdive and conducted in a dry air testing environment. A complete description of this series of tests used during Phases 2 and 3 is provided as Appendix B. Since this testing system was unavailable for use during Phase 1, a scaled-down variant of the MRPM was used during that phase, and a complete description of this modified MRPM is provided as Appendix A. All phases of this testing were conducted in the NEDU physiology lab at ambient air temperature, approximately 78 °F (25.6 °C).

TERMINATION CRITERIA

Although diver-subjects always had the option to terminate a dive voluntarily, significant concern for their safety was expressed not only by the Institutional Review Committee [(IRB), formerly known as Committee for the Protection of Human Subjects (CPHS)], but also by the researchers. Therefore, a specific and detailed list of involuntary termination criteria was developed and implemented throughout all three phases. Any diver meeting one or more of these criteria exited the water and, if his condition was deemed to be safe by the Medical Monitor and Diving Medical Officer, he or she then completed the remainder of the protocol. Table 1 shows these criteria.

Table 1.
Diver Termination Criteria

1. When the diver-subject requests termination, for any reason.
2. When the diver-subject is unable to maintain the minimum watt load setting (10 watts) on the cycle ergometer.
3. When the rectal temperature >104 °F (40 °C) continuously for 5 min or >104.9 °F (40.5 °C) at any time.
4. When significant ECG abnormalities (6 or more pre-ventricular contractions per minute; also couplets, bigeminy, or trigeminy) are present.
5. When the diver-subject's SINDBAD cognitive performance on any test cycle decreases 50% from the initial in-water test results for that particular dive.
6. When the exercising diver-subject has completed the maximum scheduled dive duration.

PHASE-SPECIFIC DESCRIPTIONS

Phase 1

Participants

A total of 21 U.S. Navy divers carried out these dives.

Acclimation

Heat acclimation was accomplished by requiring diver-subjects to perform all aerobic cycle conditioning (Appendix D) in the EC at NEDU, with temperature set at 94 °F (34.4 °C) and relative humidity at 50%. Diver-subjects also cycled an additional two hours three times per week in the EC to maintain overall cycling conditioning once testing had started.

Diver Dress

Diver dress for Phase 1 consisted of cotton T-shirt, swim trunks, and diver booties. The testing schedules for exercise state (rest versus exercise) and T_w were not randomized during this phase because of concern for diver safety based on studies completed at the Naval Medical Research Center (NMRC), formerly known as Navy Medical Research Institute (NMRI).[16] Although 94 °F (34.4 °C) was felt to be a safe temperature to start exercise dives, resting dives were completed before exercise dives at each study temperature.

Temperature

Two sets of test dives were conducted: the first, with the diver at rest; the second, with the diver exercising on an underwater cycle ergometer. Exercise rate was initially intended to be approximately 60% of each diver's $\dot{V}O_2$ max, as determined from a progressive intensity, continuous effort treadmill protocol. However, this rate was determined to be impractical; therefore, during Phase 1 testing the exercise work rate was fixed at 50 watts for all diver-subjects. This wattage was used because previous NEDU testing had determined this to approximate an oxygen consumption of 1.5 L/min, a standard combat swimmer pace.[4]

A baseline 4-hour exercise dive was conducted at 78 °F (25.6 °C) to ensure that an appropriate level of cycle training had been reached and that any decrement in performance at the study temperatures could be attributed to thermal conditions rather than to insufficient training. Test dives were conducted at 94, 96.5, 99, and 101.5 °F (34.4, 35.8, 37.2, and 38.6 °C).

Test Repetition

SINDBAD tests were performed predive, postdive, and at repeated intervals during each dive. All diver-subjects completed the pre- and postdive tests. In-water assessments were conducted at one-hour intervals for all resting dives. Assessments during the exercise dives were conducted at one-hour intervals at 78 °F (25.6 °C) and 94 °F (34.4 °C) and at 30-minute intervals during the 96.5, 99, and 101.5 °F (35.8, 37.2, and 38.6 °C) dives. Test dives continued until the diver met any of the termination criteria listed in Table 1. Maximum test dive duration for resting dives was eight hours, and maximum duration for exercise dives was four hours. The number of in-water repetitions of the SINDBAD tests completed before dive termination varied greatly among diver-subjects and across conditions: the numbers ranged from 1 to 7 at 94 °F (34.4 °C) and from 1 to 3 at 101.5 °F (38.6 °C). Therefore, the in-water performance analysis for each SINDBAD test was limited to a comparison of the first in-water score at the start of the dive to the score on the last test completed before the dive terminated. Diver-subjects who completed only one in-water SINDBAD assessment were not included in this analysis.

Phase 2

Participants

A total of 21 U.S. Navy divers carried out these dives.

In Phase 2 some conditions were varied: method of acclimation and diver dress, in addition to water temperatures.

Acclimation

Following the end of the non-heat aerobic conditioning period, diver-subjects were randomized by their $\dot{V}O_2$ max levels into two groups for heat acclimation. Acclimation Group 1 (N = 11) underwent a two-week period of "wet" heat exposure in the NEDU test pool: one hour of underwater cycling five days per week, with water temperature maintained at 94 °F (34.4 °C). Diver-subjects also cycled an additional two hours three times per week in a non-heat environment to maintain overall cycling conditioning. Acclimation Group 2 (N = 10) underwent a two-week period of "dry" heat exposure in the NEDU environmental chamber, with temperature set at 94 °F (34.4 °C) and relative humidity at 50%. This heat exposure consisted of one hour of cycling five days per week. In addition, each diver was required to cycle for an additional two hours three times per week in a non-heat environment to maintain overall cycling conditioning.

Diver Dress

Three different diver dress configurations were used during the test dives: "dive skin," "dry suit," and "dry suit with MK 21." The testing schedule for diver dress and water temperature was randomized.

Temperature

A baseline four-hour exercise dive was conducted at 94 °F (34.4 °C) to ensure that an appropriate level of cycle conditioning had been reached and that any decrement in performance at the study temperatures and with the diver dress could be attributed to thermal conditions rather than to insufficient training. No 78 °F (25.6 °C), four-hour exercise baseline dives were required, since no differences had been noted between 78 and 94 °F (25.6 and 34.4 °C) baseline dive endurance during Phase 1 testing. Test dives were conducted at 90, 94, 96.5, and 99 °F (32.2, 34.4, 35.8, and 37.2 °C). The temperatures varied among the diver dress configurations: dive skin dives were conducted at 96.5 and 99 °F (35.8 and 37.2 °C); dry suit dives were conducted at 90, 94, and 96.5 °F (32.2, 34.4, and 35.8 °C). Dry suit with MK 21 dives were conducted only at 96.5 °F (35.8 °C).

Test Repetition

SINDBAD tests were performed at 30-minute intervals during each dive, beginning immediately after the diver got settled in the water and continuing until the dive terminated. Dives began at a workload of 50 watts. As the diver fatigued and was no longer able to maintain 60 ± 5 rpm on the cycle ergometer, workload was decreased in 10-watt increments. The dive continued until the diver was unable to maintain the 10-watt rate, the lowest wattage setting on the cycle ergometer, or until the diver met other termination criteria. The maximum dive duration was four hours. The number of in-water repetitions of the SINDBAD tests completed before dive termination varied between 2 and 5 for the 94 °F (34.4 °C) baseline dive and between 1 and 5 for the various test dives. The in-water performance analysis for each SINDBAD test was limited to comparing the first in-water score at the start of the dive to the score on the last test completed before dive termination. Diver-subjects who completed only one in-water SINDBAD assessment were not included in this analysis.

Phase 3

Participants

A total of 24 U.S. Navy divers participated in Phase 3.

Heat Acclimation Group

Following the end of the aerobic conditioning phase, diver-subjects were randomized by their $\dot{V}O_2$ max into two groups for heat acclimation. Acclimation Group 1 (N = 12) underwent two weeks of "wet" heat exposure in the NEDU test pool. These exposures consisted of two-hour underwater cycling periods five days per week, with the water temperature maintained at 94 ± 0.5 °F. Acclimation Group 2 (N = 12) underwent two weeks of "wet" heat exposure in the NEDU OSF, with water temperature set at 98 ± 0.5 °F. These exposures consisted of one hour of underwater cycling five days per week. Acclimation Group 2 diver-subjects also cycled for an additional hour, two times per week in a non-heat environment.

Diver Dress

Two different diver dress configurations were used during the test dives: "dive skin" and "dry suit."

Exercise Type

Two different types of exercise — cycling and finning — were used during the test dives. During the cycling test dives, workload was set at 30 watts and was not decreased or increased during the dive. During the fin-swim exercise dives, workload was set at 50 watts, as based on strain gauge calibrations.

Temperature

A 4-hour baseline verification exercise dive was conducted in swimsuits at 94 ± 0.5 °F to ensure that an appropriate level of cycle conditioning had been reached. Thereafter, any decrement in performance could be attributed to thermal conditions and, at the study temperatures, to diver dress and/or to exercise conditions, rather than to insufficient training. Test dives were conducted at 90, 96.5, 98, 99, and 101.5 °F (32.2, 35.8, 36.7, 37.2, and 38.6 °C). The temperatures varied among the diver dress and exercise configurations. Cycling dive skin dives were conducted at 96.5, 99, and 101.5 °F (35.8, 37.2, and 38.6 °C). Fin-swim dive skin dives were conducted at 98 and 99 °F (36.7 and 37.2 °C), while fin-swim dry suit dives were conducted at 90 and 96.5 °F (32.2 and 35.8 °C).

Test Repetition

The baseline verification dive began with a workload of 50 watts. As the diver fatigued and was no longer able to maintain 60 ± 5 rpm on the cycle ergometer, workload was decreased in 10-watt increments. The dive continued until the diver was unable to maintain a level of 10 watts, the lowest wattage setting on the cycle ergometer, or until the diver met other termination criteria. The maximum dive duration for the exercise test dives was four hours. SINDBAD tests, beginning immediately after the diver got settled in the water and continuing until dive termination, were performed at 30-minute intervals during each dive. The number of in-water repetitions of the SINDBAD tests completed before dive termination varied between 3 and 5 for the 94 °F (34.4 °C) baseline verification dive and between 1 and 5 for the various test dives. Therefore, the in-water performance analysis for each SINDBAD test was limited to comparing the first in-water score at the start of the dive to the score on the last test completed before dive termination. Diver-subjects who completed only one in-water SINDBAD assessment were not included in this comparative analysis. In this study, this small sample size therefore excluded analysis of the test repetition variable to all but the baseline verification dive and the 96.5 °F (35.8 °C) cycling dive skin.

RESULTS

STATISTICS

Using Navy divers as research subjects for multi-year studies limits the statistical analysis of the resulting data, because many divers transfer during the course of the study.

The power of a statistical test lies in its ability to detect a difference between two or more observed means.[17] In studies with low power, insignificant results do not necessarily mean that no effect is present. In fact, an effect may be present, but because of the low power of the analysis, the presence of this effect is not illustrated by a statistically significant result. Low power results from a small size of a sample and/or

of an effect (a result indicating the extent to which the groups differ on the dependent variable). Both low power and small sample size affected the statistical analysis of this study. Therefore, to ensure that the sample sizes were as large as possible, the statistical analyses had to assume that the dives were independent.

Arguably, this was not actually the situation, since the same diver participated in multiple different dives. However, carryover effects from one dive to another were minimal, because the participants had conducted sufficient trials with the SINDBAD before the experimental testing to preclude any practice effect.

Results are reported separately for each of the three phases of the experiment. Although the data are generally analyzed independently for each study, data from the different studies are combined on some occasions to allow certain comparisons to be made. In addition, results for the SINDBAD and for the SOF MRPM testing are presented in separate sections.

SYSTEM FOR INVESTIGATION OF DIVERS' BEHAVIOR AT DEPTH (SINDBAD) RESULTS

Phase 1: SINDBAD Results

Results from each of the five different SINDBAD tests are shown in Table 2. The number of times the test was administered was lower for the high-temperature dives than for those at lower temperatures, because durations of the high-temperature dives were shorter than those at lower temperatures.

Table 2.
SINDBAD Data from Phase 1 (see **METHODS** for an explanation of how the values are calculated.)

			Key-insertion score		Stylus test score		Visual reaction time (sec)		Visual digit span (# correct responses)		Operation test score	
		N	Mean	St. dev	Mean	St. dev	Mean	St. dev	Mean	St. dev	Mean	St. dev
78 °F												
Exercise	First	18	38.1	7.0	145.9	12.1	0.32	0.1	30.9	12.2	5.5	0.8
	Last	18	40.3	6.5	145.9	19.9	0.29	0.0	28.4	10.7	5.2	1.4
94 °F												
Resting	First	18	35.3	12.9	150.4	40.0	0.29	0.0	28.9	9.0	5.2	1.0
	Last	18	28.1	13.4	152.0	27.0	0.29	0.1	32.3	11.6	5.2	1.3
Exercise	First	19	42.4	6.8	146.3	16.8	0.33	0.1	27.4	8.3	5.5	1.1
	Last	18	42.9	10.4	148.7	24.7	0.32	0.1	25.8	10.3	5.2	1.2
96.5 °F												
Resting	First	7	51.7	4.8	154.7	23.6	0.29	0.0	33.7	14.5	5.0	1.0
	Last	7	50.4	7.3	155.9#	39.6	0.31	0.1	31.4	11.1	5.6*	0.7
Exercise	First	16	46.9	8.7	145.6	26.8	0.32	0.1	26.3	12.7	5.8	0.5
	Last	14	47.0	7.6	127.3	30.6	0.33	0.1	25.3	17.2	5.7	0.6
99 °F												
Resting	First	9	50.9	7.9	139.7	45.7	0.31	0.1	29.1	9.9	5.7	0.6
	Last	6	52.2	8.8	127.5	45.3	0.32	0.1	28.0	9.1	5.3	0.7
Exercise	First	13	49.5	6.9	150.8	18.5	0.34	0.0	31.5	11.3	5.5	0.6
	Last	12	48.2	8.5	138.3	21.0	0.36	0.1	24.3	13.4	5.8	0.5

Table 2 continued.

			Key-insertion score		Stylus test score		Visual reaction time (sec)		Visual digit span (# correct responses)		Operation test score	
101.5 °F												
Resting	First	5	49.0	9.5	131.4	34.2	0.36	0.1	28.6	6.4	5.5	1.2
	Last	3	56.3	15.0	151.0	26.7	0.34	0.1	22.3	22.9	3.8	1.5
Exercise	First	14	47.3	7.5	149.1	18.5	0.32	0.1	24.1	8.5	5.9	0.4
	Last	6	47.7#	9.4	133.0#	25.1	0.41	0.2	21.5	11.4	5.8	0.5
Combined 94 and 96.5 °F												
Resting	First	25	39.9	13.4	151.6	35.7	0.29	0.02	30.3	10.7	5.1	1.0
	Last	25	34.3	15.6	153.1	30.2	0.29	0.08	32.0	11.2	5.3	1.2
Exercise	First	35	44.5	7.9	145.9	21.6	0.33	0.06	26.9	10.4	5.6	0.9
	Last	32	44.7	9.4	139.3	29.1	0.32	0.07	25.6	13.5	5.4	1.0
Combined 99 and 101.5 °F												
Resting	First	14	50.2	8.2	136.7	40.8	0.33	0.07	28.9	8.6	5.6	0.8
	Last	9	53.6	10.4	135.3	40.0	0.32	0.08	26.1	13.8	4.8	1.2
Exercise	First	27	48.4	7.1	149.9	18.2	0.32	0.05	27.7	10.4	5.7	0.5
	Last	18	48.0	8.6	136.3	22.0	0.36	0.12	23.4	12.5	5.8	0.5

* = One participant fewer than those shown in the number column completed this particular test.
# = One participant more than those shown in the number column completed this particular test.

In order to keep the sample size as large as possible for the analysis, investigators decided to treat the dives as independent. In addition, it was necessary to collapse data obtained from the 94 and 96.5 °F (34.4 and 35.8 °C) dives as well as from the 99 and 101.5 °F (37.2 and 38.6 °C) dives.

Test 1.1. A two-way between-subjects analysis of variance (ANOVA) between groups was used to test the *final* in-water scores from the dives carried out at the two lower temperatures (94 and 96.5 °F [34.4 and 35.8 °C]) and those carried out at the two higher temperatures (99 and 101.5 °F [37.2 and 38.6 °C]) at both exercise and rest. This ANOVA allows an assessment of whether temperature and/or exercise has an effect.

Results 1.1. The key-insertion task showed a significant main effect of temperature (F $[1,81] = 17.3$, $p < 0.05$) and a significant interaction between temperature and exercise (F $[1,81] = 8.6$, $p < 0.05$). The main effect of exercise was not significant (F $[1,81] = 0.04$, n.s.). The data indicate that the main effect of temperature is due to a poor performance at the two lower temperatures, rather than to the two higher temperatures. The significant interaction effect is a result of a higher score in the exercise condition than in the resting condition at the lower temperature. The reverse of this was found at the higher temperatures, where the scores obtained in the resting condition were higher than those in the exercise condition.

The stylus insertion, visual reaction time, and visual digit span tests revealed no significant main effects or interactions. In the operations test the main effect of temperature was not significant (F $[1,79] = 0.1$, n.s.). However, the main effect of exercise was significant (F $[1,79] = 5.5$, $p < 0.05$). Contrary to what was expected, scores from the exercise dives were significantly better than those from the resting dives.

Test 1.2. A two-way between-subjects ANOVA was used to test the *difference* between the first and last in-water test scores.

Results 1.2. For the key-insertion task, there was a main effect of temperature (F $[1,81] = 17.3$, $p < 0.05$) and a significant interaction between temperature and exercise (F $[1,81] = 8.6$, $p < 0.05$). The main effect of exercise was not significant (F $[1,81] = 0.02$, n.s.). Data indicate that the main effects of temperature and the significant interaction effect result from the resting condition dives. In the lower temperature resting dives, performance diminished over time. However, performance over time improved in the resting dives at the higher temperatures. Performance in the exercise dives was similar at both temperatures.

For the visual reaction time test, neither main effect was significant (temperature: F $[1,80] = 0.3$, n.s.; exercise: F $[1,80] = 3.0$, n.s.). However, the interaction between the variables was significant (F $[1,80] = 4.8$, $p < 0.05$). The interaction occurred because, although scores in the resting and exercise conditions at the cooler temperatures were

similar, at the higher temperatures the resting dive scores improved and performance in the exercise dives diminished.

The visual digit span and stylus tests showed no significant main effects or interactions. For the operations test, although no main effects were significant (temperature: $F[1,79] = 2.3$, n.s.; exercise: $F[1,79] = 1.7$, n.s.), the interaction was significant ($F[1,79] = 5.3$, $p < 0.05$). The interaction resulted from improved performances between the first and the last tests at the warmer temperatures in the resting condition, compared to levels of performance that did not improve in the exercise condition.

Phase 1: SINDBAD Summary of Results

The differences between the first and last in-water scores, or differences in temperature or exercise for the last in-water score, were not significant for the stylus insertion and visual digit span tests. For the key-insertion task, although performance in the exercise conditions was similar at both temperatures, performance (as measured by the last in-water score and the difference between the first and last in-water scores) decreased in the resting condition at the higher temperatures. For the visual reaction time test, the last in-water score was higher (i.e., worse) than it was in the exercise condition. For the operations test, performance in the exercise condition was comparable at both the higher and lower temperatures. However, diver performance improved at the higher temperatures in the resting condition.

Phase 2: SINDBAD Results

The results of the SINDBAD data are shown in Table 3. The most striking finding is in the many dives for which only one test was carried out before the diver met the termination criteria and the dive was finished with no second round of the test battery being started. For all five tests Table 3 shows a reasonably large spread of scores, as indicated by the ratio of standard deviations to mean scores. Also, as found in Phase 1, no effects of temperature appeared to be consistent.

Statistical analysis of the SINDBAD data was limited, because so many diver-subjects were unable to complete at least two in-water tests. To enable statistical analysis, the dry suit dives at 90 and 94 °F (32.2 and 34.4 °C) and the dive skin dives at 96.5 and 99 °F (35.8 and 37.2 °C) were collapsed (see Table 3). Because the numbers of last in-water scores for the dry suit dives at 96.5 °F (35.8 °C) were so small, these scores were not included in the analysis.

Table 3.
SINDBAD Data from Phase 2

			Key-insertion score		Stylus test score		Visual reaction time (sec)		Visual digit span (# correct responses)		Operation test score	
		N	Mean	St. dev	Mean	St. dev	Mean	St. dev	Mean	St. dev	Mean	St. dev
90 °F												
Dry suit	First	11	21.6	6.5	135.0	35.6	0.35	0.14	28.6	9.6	4.82	2.05
	Last	6	24.7	5.4	139.3	18.8	0.29	0.03	25.8	14.4	4.89	1.77
94 °F												
Dry suit	First	15	20.8	5.9	140.3	21.2	0.54	0.77	19.9	10.1	4.89	1.94
	Last	6	22.2	4.6	112.0	47.0	0.30	0.03	21.3	14.9	5.67	0.52
Baseline	First	21	46.6	7.6	158.0	14.7	0.31	0.05	26.1	8.2	4.48	1.82
	Last	21	48.9	10.1	147.1	30.8	0.29	0.04	24.0	13.8	4.98	1.58
96.5 °F												
Dive skin	First	18	50.7	8.0	153.8	21.1	0.31	0.06	28.2	12.9	5.09	1.53
	Last	15	50.0	8.8	130.7	26.4	0.31	0.05	27.7	15.0	4.78	1.92
Dry suit	First	3	17.0	6.2	120.3	27.2	0.35	0.09	23.3	4.5	5.11	1.54
	Last	1	16.0[#]	-	-	-	-	-	-	-	-	-
MK 21	First	8	18.3	6.3	125.3	15.6	0.35	0.08	27.5	14.8	4.50	1.38
	Last	2	18.0	2.8	123.0	14.1	0.30	0.02	5.5	0.7	3.00	1.41
Dry suit	First	18	50.7	8.0	153.8	21.1	0.31	0.06	28.2	12.9	5.09	1.53
+ cooling	Last	15	50.0	8.8	130.7	26.4	0.31	0.05	27.7	15.0	4.78	1.92

Table 3 continued.

			Key-insertion score		Stylus test score		Visual reaction time (sec)		Visual digit span (# correct responses)		Operation test score	
99 °F												
Dive skin	First	20	49.3	7.2	155.1	24.8	0.32	0.06	21.1	11.0	5.02	1.58
	Last	5#	50.8	3.3	135.4	18.1	0.34	0.07	21.6	2.7	5.67*	0.67
90 and 94 °F												
Dry suit	First	26	21.2	6.1	138.0	27.7	0.46	0.59	23.6	10.6	4.9	1.9
	Last	12	23.4	5.0	125.7	37.0	0.29	0.03	23.6	14.2	5.3	1.3
96.5 and 99 °F												
Dive skin	First	38	50.0	7.5	154.5	22.8	0.31	0.06	24.4	12.3	4.5	1.8
	Last	20	50.2	7.7	131.9	24.2	0.32	0.06	26.2	13.2	5.0	1.6

* = One participant fewer than those shown in the number column completed this particular test.
# = Only one participant completed the key-insertion task.

Test 2.1. A one-way between-subjects analysis was carried out to assess the effects of dress. The dependent variable was the difference between the first and last in-water scores for each of the five tests.

Results 2.1. Dress showed no significant effects in any of the five tests.

Test 2.2. To assess the effect of dress, a one-way between-subjects ANOVA was carried out with the first in-water score as the dependent variable.

Results 2.2. Significant differences were found for the key-insertion ($F [2,82] = 137.5$, $p < 0.05$) and stylus tests ($F [2,82] = 5.6$, $p < 0.05$). In both cases, results from the dry suit dives were significantly lower than those from the swimsuited and dive skin dives. This difference suggests that divers may have problems carrying out their tasks because they are wearing dry suits.

Test 2.3. A one-way between-subjects ANOVA was carried out, with the difference between the first and the last in-water scores as the dependent variable.

Results 2.3. No differences between the first and last in-water scores were found to be significant.

Test 2.4. A one-way between-subjects ANOVA was carried out, with the last in-water score as the dependent variable.

Results 2.4. Only the key-insertion task showed a significant effect of dress ($F [2,50] = 46.1$, $p < 0.05$) for any of the five dependent variables. The scores obtained in the dry suit dives were significantly worse than those obtained during the swimsuited or dive skin dives.

Phase 2: SINDBAD Summary of Results

The only significant finding from the Phase 2 results was that, in terms of absolute performance, the key-insertion task was performed less effectively in the dry suit dives than in the swimsuited and skin dives. However, the type of dress did not significantly hamper performance.

Phase 3: SINDBAD Results

As in Phase 2, for many dives the diver-subjects were not in the water sufficiently long to take the SINDBAD tests for a second time (see Table 4). Therefore, for statistical analysis some cells were collapsed. Comparisons were made between the swimsuited dives at 94 °F (34.4 °C); the dive skin dives at 96.5 °F (35.8 °C); the dive skin dives at 98, 99, and 101.5 °F (36.7, 37.2, and 38.6 °C); and the dry suit dives at 90 and 96.5 °F (32.2 and 35.8 °C). Comparisons also were made among the five conditions of the first in-water score, the last in-water score, and the differences between the first and last in-water scores for each of the five tests.

Test 3.1. One-way independent sample ANOVAs were carried out for each of the five SINDBAD tests for the first in-water scores.

Results 3.1. The first in-water score on the key insertion task for the dry suit dives was significantly lower than those for all the other dive conditions ($F [3,126] = 67.7$, $p < 0.05$); no other differences were significant. Because performance for the swimsuited dive was significantly better than that for the dry suit dive, differences for the stylus insertion task were also significant ($F [3,125] = 3.5$, $p < 0.05$). No other differences were found to be significant. Differences for the operations task were significant ($F [3,126] = 4.4$, $p < 0.05$). Performance during the swimsuited dive was significantly better than that during the dry suit dive but was significantly worse than the performance during the combination of skin dives at 98, 99, and 101.5 °F (36.7, 37.2, and 38.6 °C).

Test 3.2. One-way independent sample ANOVAs were performed for each of the five SINDBAD tests for the last in-water scores. Since the dry suit dives afforded only five data points, these dives were not included in this analysis.

Results 3.2. No significant differences were found for any of the five tests.

Test 3.3. One-way independent sample ANOVAs were completed for each of the five SINDBAD tests for the difference between the first and last in-water scores. As in Test 3.2, the dry suit dives were not included in this analysis.

Results 3.3. No significant differences were found for any of the five tests.

Phase 3: SINDBAD Summary of Results

The SINDBAD data show that, as in Phase 2, wearing a dry suit diminishes performance of the key-insertion task. Also, when compared to results during the swimsuited dives, performance of the stylus insertion task is poorer than during the dry suit dives.

Table 4.
SINDBAD Data from Phase 3

			Key-insertion score		Stylus test score		Visual reaction time (sec)		Visual digit span (# correct responses)		Operation test score	
		N	Mean	St. dev	Mean	St. dev	Mean	St. dev	Mean	St. dev	Mean	St. dev
90 °F												
Dry suit, Fin	First	10	18.3	5.6	113.6	51.5	0.38*	0.15	32.0	16.6	5.7	0.9
	Last	4	15.3	5.2	128.5	15.0	0.32	0.11	22.5	5.5	5.3	0.8
94 °F												
Swimsuited, Cycle, 50W	First	23	42.6	16.1	149.0	40.7	0.41	0.57	27.6	12.8	4.6	1.7
	Last	23	43.9	5.8	140.4	37.6	0.31	0.10	24.7	11.7	5.1*	1.1
96.5 °F												
Skin, Cycle, 30W	First	19	44.2	8.3	147.5	35.9	0.30*	0.04	31.9	12.9	5.1^	1.5
	Last	16	42.3	8.1	134.6	34.4	0.32	0.06	26.8	9.3	5.4	1.2
Dry suit, Fin	First	8	19.4	6.2	118.3	19.3	0.38	0.07	27.1	10.6	5.5	0.7
	Last	1	20	-	162.0	-	0	-	43.0	-	6.0	-
98 °F												
Skin, Fin	First	19	45.7	6.5	147.2	31.8	0.31	0.04	31.5	11.7	5.5*	0.9
	Last	7	47.3	5.9	129.4	35.0	0.36	0.10	32.6	14.1	6.0	0

Table 4 continued.

			Key insertion score		Stylus test score		Visual reaction time (sec)		Visual digit span (# correct responses)		Operation test score	
99 °F												
Skin, Cycle, 30W	First	15	44.1	6.5	146.3	39.9	0.32	0.07	28.1	10.7	5.6#	0.6
	Last	7	47.9	16.8#	133.7	36.4	0.31	0.04	27.1	15.2	5.4	1.0
Skin, Fin	First	18	46.2	6.5	135.6	39.4	0.35	0.12	34.3	15.8	5.7	0.5
	Last	3	48.8	7.3#	149.0	39.4	0.46	0.46	33.7	4.2	6.0	0
101.5 °F												
Skin, Cycle, 30W	First	18	45.6	6.7	142.7	29.6	0.34	0.10	28.3	15.5	5.1*	1.0
	Last	0	-	-	-	-	-	-	-	-	-	-
90 and 96.5 °F												
Dry suit	First	18	18.8	5.7	115.7	39.5	0.38	0.12	29.8	14.1	5.6	0.8
	Last	5	16.2	5.0	135.2	19.8	0.26	0.17	26.6	10.3	5.5	0.7
98, 99 and 101.5 °F												
Dive skin	First	70	45.5	6.4	142.8	35.1	0.33	0.09	30.7	13.6	5.5	0.8
	Last	17	47.9	11.8	134.3	35.8	0.35	0.18	30.3	13.3	5.7	0.7

* = One participant fewer than those shown in the number column completed this particular test.
# = One participant more than those shown in the number column completed this particular test.
^ = Two participants more than those shown in the number column completed this particular test.

SPECIAL OPERATIONS FORCES MISSION-RELATED PERFORMANCE MEASURES (SOF MRPM): Results

Phase 1: SOF MRPM Results

Data from the four performance battery tests in Phase 1 are outlined in Table 5. The values are in percentages [(postscore/prescore) x 100]. To illustrate, if a participant completes 10 pull-ups in the baseline test before the dive and 8 pull-ups after the dive, his score is 80%.

Table 5.
SOF MRPM Phase 1 Performance Data Summary
[values are (postscore/prescore) x 100]

Water temp		HGDH* Max	HGNDH# Max	Steps	Pull-ups
78 °F					
Exercise	**Mean**	**103.8**	**99.8**	**100.5**	**92.7**
	No. of dives	18	18	16	17
	Std. Dev	11.4	10.4	10.4	18.9
94 °F					
Resting	**Mean**	**99.6**	**103.0**	**95.2**	**96.7**
	No. of dives	18	18	18	17
	Std. Dev	7.2	11.0	14.0	18.2
Exercise	**Mean**	**96.8**	**101.5**	**92.4**	**104.9**
	No. of dives	15	15	13	15
	Std. Dev	8.6	11.8	13.0	28.9
96.5 °F					
Resting	**Mean**	**99.1**	**99.9**	**96.4**	**105.4**
	No. of dives	37	7	7	13
	Std. Dev	3.4	6.5	5.8	22.5
Exercise	**Mean**	**95.8**	**96.3**	**94.4**	**96.0**
	No. of dives	15	15	14	13
	Std. Dev	8.9	10.9	21.3	22.5
99 °F					
Resting	**Mean**	**101.3**	**99.3**	**96.8**	**94.2**
	No. of dives	6	6	6	5
	Std. Dev	7.5	8.2	9.0	15.1
Exercise	**Mean**	**99.2**	**98.1**	**94.7**	**99.8**
	No. of dives	14	14	14	14
	Std. Dev	9.3	9.7	7.8	14.8
101.5 °F					
Resting	**Mean**	**100.8**	**100.0**	**98.0**	**97.0**
	No. of dives	5	5	5	4
	Std. Dev	7.6	7.0	4.0	6.0
Exercise	**Mean**	**100.8**	**99.0**	**90.1**	**101.8**
	No. of dives	11	11	12	10
	Std. Dev	12.0	8.8	11.6	9.2

* HGDH is handgrip, dominant hand grip; # HGNDH is handgrip, nondominant hand.

To keep the sample size as high as possible for the analysis, the dives again were treated as independent. In addition, to improve the sample sizes to allow meaningful statistical analysis, it was necessary to collapse the data obtained from the 94 and 96.5 °F (34.4 and 35.8 °C) dives and from the 99 and 101.5 °F (37.2 and 38.6 °C) dives. Table 6 shows the collapsed data.

Table 6.
SOF MRPM Phase 1 Collapsed Data Summary
[values are (postscore/prescore) x 100]

Water temp		HGDH* Max	HGNDH# Max	Steps	Pull-ups
94 and 96.5 °F					
Resting	**Mean**	**99.4**	**102.1**	**99.3**	**95.6**
	No. of dives	25	25	24	25
	Std. Dev	6.3	9.9	16.5	12.2
Exercise	**Mean**	**96.3**	**98.9**	**100.8**	**93.4**
	No. of dives	30	30	28	27
	Std. Dev	8.6	11.5	26.0	17.4
99 and 101.5 °F					
Resting	**Mean**	**101.1**	**99.6**	**95.4**	**97.4**
	No. of dives	11	11	9	11
	Std. Dev	7.1	7.3	11.4	6.9
Exercise	**Mean**	**99.9**	**98.5**	**100.6**	**92.6**
	No. of dives	25	25	24	26
	Std. Dev	10.4	9.2	12.6	9.8

* HGDH is handgrip, dominant hand.
\# HGNDH is handgrip, nondominant hand.

Test 1.1. A two-way between-participants ANOVA was used to compare the exercise and resting conditions of the two temperature groups for each of the four performance tests.

Results 1.1. As data in Table 6 suggest, no significant main effects or interactions were found to result from exercise or temperature.

Phase 1: SOF MRPM Summary of Results

No significant main effects or interactions were found to result from the influence of exercise or temperature.

Phase 2: SOF MRPM Results

The results of the performance battery are shown in Table 7. The same tasks were performed as in Phase 1, with the addition of a handgrip endurance test for each hand and a shooting task (see Appendices A and B).

Table 7.
SOF MRPM Phase 2 Performance Data Summary
[values are (postscore/prescore) x 100]

Water temp (°F)		HGRH* max	HGRH time	HGLH# max	HGLH time	Steps	Pull-ups	Shooting
90 °F								
Dry suit	**Mean**	**95.3**	**82.7**	**96.5**	**77.7**	**95.6**	**105.0**	**88.9**
	No. of dives	12	12	11	11	9	11	12
	Std. Dev	15.3	18.1	21.3	18.7	9.4	19.1	12.3
94 °F								
Dry suit	**Mean**	**97.3**	**85.8**	**94.8**	**90.3**	**95.2**	**107.2**	**89.7**
	No. of dives	19	19	19	19	17	18	19
	Std. Dev	13.4	28.9	12.6	24.2	6.6	18.2	18.8
Validation (Swimsuited)	**Mean**	**99.9**	**99.8**	**101.4**	**94.2**	**105.2**	**109.8**	**76.8**
	No. of dives	20	20	20	20	18	19	20
	Std. Dev	10.6	29.6	8.8	25.0	8.8	12.7	12.0
96.5 °F								
Dry suit	**Mean**	**94.8**	**73.9**	**85.8**	**78.3**	**94.6**	**99.1**	**92.9**
	No. of dives	8	8	8	8	7	7	8
	Std. Dev	5.2	23.3	9.8	2.8	4.7	13.6	15.2
Skin	**Mean**	**92.6**	**82.4**	**90.7**	**76.9**	**89.6**	**103.1**	**91.6**
	No. of dives	19	19	18	18	16	17	19
	Std. Dev	12.3	18.8	13.6	19.8	6.8	18.6	17.8
99 °F								
Skin	**Mean**	**91.8**	**87.4**	**91.5**	**87.2**	**92.3**	**103.8**	**90.7**
	No. of dives	18	18	18	17	16	16	18
	Std. Dev	15.9	24.9	13.4	26.6	6.4	24.6	17.1

* HGRH is handgrip, right hand.
# HGLH is handgrip, left hand.

Test 2.1. Differences in the dependent variables for the data available from the dives carried out in the dry suit at 90, 94, and 96.5 °F (32.2, 34.4, and 35.8 °C) were compared with an independent ANOVA (see Table 7).

Results 2.1. No significant differences were found for the seven variables analyzed (see Table 7).

Test 2.2. A comparison was made between the dives carried out at 94 °F (34.4 °C) with divers either in dry suits or swimsuited. As there were only two dives to compare, within subjects t-tests were used.

Results 2.2. Performances after the swimsuited dives for the steps ($t = 4.3$, $df = 16$, $p < 0.05$) and maximum handgrip left hand ($t = 3.1$, $df = 18$, $p < 0.05$) were significantly better than were those for the dry suit dives. However, the shooting task performance was significantly better after the dry suit dives than after the swimsuited dives ($t = -3.7$, $df = 18$, $p < 0.05$). The differences for all other tasks were not significant.

Test 2.3. A comparison was made between the dives in which the participants were wearing dive skins at 96.5 and 99 °F (35.8 and 37.2 °C). As was the case in Test 2.2, only two dives were compared; therefore, within subjects t-tests were used.

Results 2.3. No significant differences were found for the seven variables analyzed.

Phase 2: SOF MRPM Summary of Results

No significant differences were found between the dry suit dives at the three different temperatures. After the swimsuited dives, performance for both step and maximum handgrip left hand tests was significantly better than it had been. The performance of the shooting task after the dry suit dives at 94 °F (34.4 °C) was significantly better than after the swimsuited dives at 94 °F (34.4 °C). A comparison of the performance on the tasks after the skin dives at 96.5 and 99 °F (35.8 and 37.2 °C) did not reveal any significant differences in task performance.

Phase 3: SOF MRPM Results

No Phase 3 SOF MRPM results are to be presented.

DISCUSSION

SINDBAD

The SINDBAD testing provided no evidence of any water temperature effect on cognitive performance. As a result of the marked changes in diver endurance and other physiological measures (see Volume 1 of this report), significant degradations were expected in these results from the first to the final SINDBAD tests in-water. Some possible explanations for this finding are presented here.

Previous research. An examination of past research on the effects of heat stress in a dry environment neither supports nor refutes findings from Volume 2 of this study. The key-insertion task and stylus test both measure psychomotor components of object manipulation and manual dexterity. Although heat effects on psychomotor performance have been reported, studies examining the effect of heat in a dry environment show contradictions. To illustrate, a study conducted in 1950 concluded that the ability to align pointers was poorer at ambient temperatures above 90 °F (32.2 °C) than below this temperature.[18] However, a later study reported better steadiness at high temperatures (126 °F [52.2 °C]) than at lower temperatures.[19] Therefore, although previous research shows a general overall trend of impairment in psychomotor skills, the findings are not consistent.[20]

As for psychomotor skills, it is difficult to draw firm conclusions from the literature about how heat affects reaction time. Studies report increases, decreases, and no change in reaction times as a result of dry heat exposure.[20] However, research in the effects of heat on complex mental and memory tasks shows results that are more consistent than those for the effects of heat on psychomotor performance. After about three hours, an ability to perform complex mental tasks deteriorates in air temperatures greater than 90 °F (32.2 °C).[20] Thus, since the only consistent finding appears to be that heat detrimentally affects the performance of complex mental and memory tasks, the literature provides little help in explaining how heat stress affects

cognitive performance. In fact, there could be no difference: cognitive performance may not suffer from diving in warm waters. However, in the study described in this volume, the clinical condition of the divers exiting the water after the high temperature and/or long duration dives suggests that warm water diving did not diminish cognitive performance.

Experimental method effects. During dives in water temperatures greater than 96.5 °F (35.8 °C) under all conditions (with swimsuited and resting dives as the only exceptions), diver-subjects were all hypotensive, tachycardic, flushed, and mildly to moderately dehydrated, as they had lost as much as 16 pounds or 6% of their total body weights. At temperatures greater than 96.5 °F (35.8 °C) during their warm water exposures, all diver-subjects reported heat stress symptoms including decreased coordination, lightheadedness, and confusion. With these clinical signs and symptoms present, cognitive decrement occurred during their warm water exposures.

These effects were not manifested in the performance of the SINDBAD test, however, because of the timing of the final in-water test. As described in **METHODS**, SINDBAD testing was conducted at regular intervals, every 30 or 60 minutes, depending on the expected dive duration (longer dives at temperatures < 96.5 °F (< 35.8 °C), and shorter at temperatures > 96.5 °F (> 35.8 °C) after a diver entered the water. Although comparing the first and the final in-water scores should have shown the greatest level of decrement, it was not possible to perform the final in-water testing immediately before termination of a dive. Symptoms of heat stress resulting in a self-termination or a rise in core temperature until the diver met the termination criteria (see Table 1) occurred rapidly. Therefore, these events were likely to occur *after* the last in-water SINDBAD test was completed, when the obvious cognitive deficits present after the diver had been removed from the water were finally manifested.

Future warm and cold water studies with in-water cognitive testing should use participants' core temperatures, rather than specific time intervals, as indicators of when the test should be carried out. Diver-subjects would perform the tasks less frequently at the beginning but more frequently at the end of the dives. This timing would allow an increasingly detailed evaluation of how quickly cognitive performance declines as core temperature changes. Furthermore, it would control for the fact that different divers remain in the water for varying time intervals.

Test sensitivity. The number of participants in the experiment was fairly low, a number which may not have provided sufficient power to allow significant differences to be detected. The SINDBAD tests employed during this study may not be sufficiently sensitive to measure any gradual deficit in cognitive performance prior to the large cognitive drop before a dive terminates. In addition, the equipment worn by a diver has been shown to affect performance of in-water SINDBAD tasks, and these effects can be confounded with environmental effects.

Individual differences. Another factor to be considered includes individual differences in heat tolerance. For example, individuals with high proportions of body fat have a low heat tolerance, because their capacity to store heat is reduced.[21] As the

SINDBAD test scores suggest, the variation in the scores seems reasonably large. However, because of constraints on the participants, it was not possible to examine the test scores with a repeated measures design that requires each test subject in the analysis to have participated in every level of the experiment. For example, in Phase 1 the participant was to complete a dive at 94, 96.5, 99, and 101.5 °F (34.4, 35.8, 37.2, and 38.6 °C) in both the resting and exercise conditions. If one of these dives was not completed, then the test subject could not be included in the statistical analysis. Therefore, to keep the sample size as high as possible for the analysis, it was necessary to treat the dives as independent.

Equipment effects. Other factors that influenced performance on the SINDBAD test were the dry suit gloves and the fin-swimming dives. The purpose of the testing was to determine the cognitive and the physical performance of diver-subjects wearing the equivalent of the contaminated water diving ensemble. Therefore, wearing the dry suit gloves significantly reduced divers' manual dexterity. In the fin-swimming dives it was difficult for the divers to maintain the appropriate position in the water column to carry out the SINDBAD test. Since finning resistance was based on strain gauge readings and an elastic tether was attached to the diver, any slowing or decreasing effort in finning resulted in the diver-subject being pulled backward by the elastic tether and away from the SINDBAD response pad.

SOF MRPM

The SOF MRPM testing also did not seem to provide evidence of an effect of water temperature on test performance. Because of the marked changes in diver endurance and other physiological measures (see Volume 1 of this report), results were expected to show significant degradations as water temperature and degree of thermal protection (diver dress) increased. Again, several factors probably explain why this was not seen.

The first explanation could be that there is no difference: that is, physical performance does not suffer as a result of diving in warm waters. However, the clinical condition of these divers exiting the water after the high temperature and/or long duration dives suggests that this was not the case. Furthermore, because of muscle fatigue alone, any performance measure after a four-hour endurance event would be expected to decrease. Again, all the clinical signs and symptoms support the conclusion that warm water exposures affect performance decrements.

A conclusion that could be drawn is that our testing vehicle is unable to detect this loss of physical performance. However, this conclusion is contrary to multiple studies in thermally stressful scenarios (cold and hot, wet and dry) in which the SOF MRPM has successfully measured significant degradation of performance following extreme thermal exposures.[14,17,22] In fact, this study conducted 98 °F (36.7 °C) temperature dives to allow comparison to other warm water diving studies in which SOF MRPM were used.

An inability to identify performance degradations following warm water exposures may be attributable to the active whole body cooling (with air-conditioned environment, water mist, fans, and cool fluid rehydration) that this study used as a

safety measure for all divers. When diver-subjects emerged from the water, they were immediately sprayed with a fine mist of cool water while a fan blew air across their bodies. As soon as they had their UBAs removed and could walk, they were moved to an air-conditioned space. This transfer usually took no longer than about five minutes, and then they were in the air-conditioned physiology lab. All of these measures increased conductive heat loss and added evaporative cooling. Once in the physiology lab, diver-subjects also were provided cool liquid for rehydration: they were allowed to choose between plain water, a diluted commercial sport drink, or a combination of the two for their rehydration fluid.

The timing to start the battery of tests affords another explanation for an inability to identify performance degradations during the warm water exposures. Because of concern for diver safety, diver-subjects were allowed to decide when they were ready to start the SOF MRPM. This regimen differed markedly from the fixed ten-minute recovery time allowed in all previous studies using the SOF MRPM system. The ten-minute recovery period allowed monitoring to occur and allowed divers to shed diving equipment, but it does not appear to allow them to recover from their warm/cold water exposures. One conclusion that seems reasonable is that, with active cooling of the type provided to the diver-subjects in this study, individuals rather quickly recover to preheat dive exposure levels.

CONCLUSIONS

The in-water cognitive performance data collected with five tests from the SINDBAD battery provided no evidence of any warm water effect on cognitive performance. Nevertheless, evidence of participants "hitting the wall" was followed by a sudden and ruinous drop in cognitive ability. If these consequences were to occur in a real operation, they would force the mission to be aborted and would disable or possibly kill the operators involved. However, that the five SINDBAD tests show no significant effect of the water temperature on diver performance illustrates that although the divers can be hot and uncomfortable, as long as their core temperatures are kept below a maximum of 102 °F (38.9 °C) [see Volume 1 of the report], the effects of temperature on cognitive performance appear to be minimal.

When compared to other warm water dive studies conducted at NEDU, the results of the SOF MRPM battery show that with active cooling, rehydration, and an extended recovery period, divers recover sufficiently to minimize performance decrements. However, these conditions may be difficult to duplicate in the field, where air-conditioned spaces are limited or nonexistent.

RECOMMENDATIONS

The following recommendations are based on results from the cognitive and performance testing completed during this three-year study. These recommendations should not be considered in isolation. Additional recommendations and a summary of all warm water diving recommendations from these studies may be found in the **RECOMMENDATIONS** section of Volume 1 of this report.

1. When divers are immersed in warm water, their cognitive performance appears to be relatively unaffected below 102 °F (38.9 °C) [see Volume 1 of the report]. However, when core temperature rises above 102 °F (38.9 °C), cognitive performance appears to decline rapidly and catastrophically. Results from the studies suggest that this decline occurs in less than 30 minutes. Thus, the exposure guidance presented in Volume 1 should be considered during mission planning. Furthermore, when possible, operators should conduct a simulation of the mission in an environment similar to that in which they will operate.

2. Individuals have different heat tolerances. These differences should be considered when operators are being selected to perform warm water missions.

3. In an operational environment it is obviously unlikely that personnel can be actively cooled, as they were in this experiment. However, when mission planning provides operators with means to hydrate and rest once they are out of the water, these means will enhance their abilities to perform subsequent tasks.

4. When studying effects of thermal exposure, investigators should consider using participant temperatures to indicate when cognitive performance should be measured rather than conducting tests at fixed time intervals.

5. Repeat the 99 °F (37.2 °C) dive skin dives (cycle exercise only) exactly as described in NEDU Protocol 00-07, and simulate actual field conditions (i.e., high air temperatures, hydration with warm water, and no active cooling). Allow diver-subjects to self-determine when they start the SOF MRPM test battery, but keep close track of this time to see how long it takes for diver-subjects to recover sufficiently to start the battery.

6. Develop a battery of tests that simulates both the cognitive and physical skills as well as the abilities required by divers in real operations. Although the SINDBAD test consists of 30 different tests of perceptual, memory, cognitive, and psychomotor abilities, only five tests were designed for in-water administration. In the last 30 years since the SINDBAD was developed, psychological and physiological research and technical progress have made enormous advances. Thus, it is now possible to develop a battery of cognitive and physical tests that will allow a task-specific submersible performance assessment tool to be developed for diving.

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APPENDIX A

DEVELOPMENT OF EXPOSURE GUIDANCE FOR WARM WATER DIVING

Principal Investigator: CDR E. T. LONG, MC, USN

NEDU Protocol
DIVER-SUBJECT DIRECTION SHEET

NAME ______________________ DATE_______________

PREDIVE

Evening before scheduled dive.

1. No alcohol 48 hours before scheduled dive.
2. No caffeine 24 hours before scheduled dive.
3. Before leaving the day before scheduled dive, get 1 Meals Ready to Eat (MRE) and 1 urine collection bottle.
4. Eat 1 MRE for the evening meal the night before the scheduled dive. (Diver may eat more than this, but at a minimum eat 1 MRE.)
5. Drink at least 1 liter of fluid (caffeine free) between 1800 and 2200 the evening before the scheduled dive. (Fluid is diver's choice, but Gatorade will be made available to take home to drink.)

Morning of scheduled dive.

1. Measure resting heart rate upon initial wakeup.
2. Collect first void of morning.
3. **DO NOT** eat or drink until after blood draw at NEDU blood lab.
4. Arrive at Physiology Lab at ________.
5. Bring dry T-shirt; wear running shoes or equivalent. (No sandals, flip-flops, etc.)

POSTDIVE

1. Follow directions after exiting the water. Measurements similar to those taken during predive in the physiology lab will be made.
2. Diver will be observed until heart rate and core temperature return to baseline (<99 °F) and fluids are drunk, and until they have urinated at least once since exiting the water and have been cleared by the DMO.
3. Diver will retain this sheet until the following morning.
4. In an emergency, call
   CDO at 230-3100 or
   Duty DMO: Dr. ______________ at pager ___________________

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APPENDIX B

DEVELOPMENT OF EXPOSURE GUIDANCE FOR WARM WATER DIVING

Principal Investigator: CDR E. T. LONG, MC, USN

NEDU Protocol

NEUROPSYCHOLOGICAL AND PHYSICAL PERFORMANCE ASSESSMENT

1. INTRODUCTION AND OBJECTIVES

The goals are to:

a. Assess the safety, from a neuropsychological and physical standpoint, of exposure to a warm water environment.

b. Ensure proper documentation of the saturation diver's neuropsychological state and physical level before and after warm water exposure.

c. Identify any residual effects of warm water exposure.

d. Use the results of these tests to provide for timely medical intervention, where indicated.

Operational performance and safety are issues in any challenging environment. Working while in extremely warm water is an unexplored subject that this study will address. The data gathered during this series of dives will assist in early identifying of potential changes in diver well being and in investigating diver reports of subtle changes in cognitive functioning, should such reports arise.

2. MATERIALS

The following will make up the evaluation battery for Phase 1 dives of this study:

PHYSICAL PERFORMANCE

a. Grip Strength Test

b. Pull-ups

c. Step-up task

COGNITIVE

a. Trail Making A and B

b. Symbol Digit Modalities Test (SDMT)

c. Wechsler's Memory Scale-R (Logical Memory I and II)

d. Tester's Workbench/Automated Neuropsychological Assessment Metrics (TWB/ANAM)

3. PROCEDURE

Each of the following will be given before and after the dives:

Grip Strength Test measures motor strength of the upper extremities. It is administered individually and takes 3–5 minutes per subject.

Pull-ups are a stable measure of upper body strength. The measurement is the total frequency of pull-ups in one trial. It is administered individually and takes about 3–5 minutes per subject.

The Step-up task is a measure of coordination and lower body strength. It constitutes the frequency of ascensions on two steps in 60 seconds. It is administered individually.

Trail Making is a measure of the subject's executive mental functioning. Specifically, this test measures attention, mental shifting, working memory, and — to a point — tremors. It has been found to be highly reliant on frontal lobe functioning. This test requires about 5 minutes to administer and is also given individually. Scores are obtained from the time it takes to complete the forms and the number of errors that are made. These two results are factored together to yield a standard score on a 10-point scale.[1]

Symbol Digit Modalities Test (SDMT) is a pencil-and-paper test for which the subject has to match numbers randomly assigned to geometrical symbols. This test assesses sustained attention, visual-spatial motor coordination, and response speed and requires about 3 minutes to administer. The SDMT gives a raw score.[2]

The Logical Memory subscale of Wechsler Memory Scale is a memory examination and is given individually. It specifically measures immediate and delayed recall as well as verbal memory. It takes about 5 minutes to administer and yields a raw score and percentage scores.[3]

The TWB/ANAM[4, 5] is a computer-based standard clinical subset of the Office of Military Performance Assessment Technology (OMPAT) Tester's Workbench (TWB). The ANAM is a set of TWB tests that have been reconfigured for use in clinical neuropsychological evaluations. Many components of the ANAM were derived from the UTCPAB/STRES Battery[6] and the Walter Reed Performance Assessment

Battery.[7] The ANAM 2000, the latest version, is purported to precisely measure mental efficiency as well as accuracy.[5]

The tests in the ANAM 2000 battery were selected for assessing sustained concentration and attention, mental flexibility, spatial processing, cognitive processing efficiency, mood, arousal/fatigue level, and short-term, long-term, and working memory. Specifically, the ANAM 2000 battery for this dive series is composed of the following subtests:

- Demographics form.
- Stanford Sleepiness Scale — Measures alertness level.
- Mood Scale 2-R — Measures current mood level (state).
- Simple Reaction Time — Measures basic psychomotor speed.
- Code Substitution (Letter/Symbol Comparison) — Measures visual scanning and learning.
- Code Substitution — Measures immediate and delayed recall.
- Running Memory Continuous Performance Task (CPT) — Measures working memory and executive functions.
- Mathematical Processing Task — Measures computational speed and working memory.
- Matching to Sample — Measures delayed recall/longer-term memory.

<u>Note</u>: These subtests are purported measures and are discussed in more detail in Reeves et al.[5]

The following will occur during the conditioning phase of the study:

1. During the first week, each assessment instrument will be performed to reach a stabilized peak performance. This level is defined as:

- ±5% baseline stability for ANAM 2000
- Physical Performance of ±5% baseline stability for the Grip Strength component and the Stair Climb component
- Pull-up frequency of ±2 of stable baseline

2. During the second week, the peak performance level of ±5% of baseline stability will be determined for the SINDBAD in the wet environment.

3. Each week except the first, a maintenance session with each task will be performed to ensure that baseline levels remain at peak performance.

4. During the conditioning phase, additional sessions will be conducted as necessary to maintain baseline measures.

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APPENDIX C

DEVELOPMENT OF EXPOSURE GUIDANCE FOR WARM WATER DIVING

Principal Investigator: CDR E. T. LONG, MC, USN

NEDU Protocol

DIVER-SUBJECT SYMPTOM QUESTIONNAIRE

		1	2	3	4	5
1.	Signs/Symptoms Oxygen Toxicity					
	a. Vision changes	[ ]	[ ]	[ ]	[ ]	[ ]
	b. Ringing in ears	[ ]	[ ]	[ ]	[ ]	[ ]
	c. Nausea	[ ]	[ ]	[ ]	[ ]	[ ]
	d. Tingling	[ ]	[ ]	[ ]	[ ]	[ ]
	e. Twitching	[ ]	[ ]	[ ]	[ ]	[ ]
	f. Irritability	[ ]	[ ]	[ ]	[ ]	[ ]
	g. Dizziness	[ ]	[ ]	[ ]	[ ]	[ ]
2.	Lightheadedness?	[ ]	[ ]	[ ]	[ ]	[ ]
3.	Weakness?	[ ]	[ ]	[ ]	[ ]	[ ]
4.	Muscle cramps?	[ ]	[ ]	[ ]	[ ]	[ ]
5.	Confusion?	[ ]	[ ]	[ ]	[ ]	[ ]
6.	Coordination: Decreased?	[ ]	[ ]	[ ]	[ ]	[ ]
7.	Thirsty?	[ ]	[ ]	[ ]	[ ]	[ ]
8.	Headache?	[ ]	[ ]	[ ]	[ ]	[ ]
9.	Rapid breathing?	[ ]	[ ]	[ ]	[ ]	[ ]
10.	Unsteady on feet?	[ ]	[ ]	[ ]	[ ]	[ ]
11.	Urge to have a bowel movement?	[ ]	[ ]	[ ]	[ ]	[ ]
12.	Do you wish to abort/terminate?	YES ____		NO ____		

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APPENDIX D

CYCLE CONDITIONING

DEVELOPMENT OF EXPOSURE GUIDANCE FOR WARM WATER DIVING

Principal Investigator: CDR E. T. LONG, MC, USN

INTRODUCTION

GENERAL

The following program of cycle conditioning is designed so that all subjects should be able to meet the desired level of cycling fitness. This conditioning program should provide sufficient training to enable all subjects to perform a four-hour cycle ride on the underwater cycle ergometers by the end of the training period. During this conditioning, a percentage of maximum heart rate (max HR) is used to ensure sufficient training resistance. To calculate max HR for the aerobic condition phase of this study, use the following equations:

$$(220 - \text{age}) \times 0.6 = 60\% \text{ max HR}$$

$$(220 - \text{age}) \times 0.75 = 75\% \text{ max HR}$$

After warming up, all subjects should adjust cycle resistance to maintain their heart rates between 60% and 75% of their calculated maximum. Cycle pedal rates should be between 75 and 90 revolutions per minute (rpm) during conditioning.

METHODS

The following plan is provided as a general guideline. Actual sessions and time schedules may vary because of the subject's level of cycling conditioning and response to training.

1st week:

4–5 sessions for a minimum of 30 minutes at 60–75% $\dot{V}O_2$ max heart rate

2nd week:

4–5 sessions for a minimum of 45 minutes at 60–75% $\dot{V}O_2$ max heart rate

3rd week:

2 sessions at 60–75% $\dot{V}O_2$ max heart rate for one hour
90-min rides Friday or Saturday

4th week:

2 sessions at 60% $\dot{V}O_2$ max heart rate for two hours
2.5-hour bike rides Friday or Saturday

5th week:

1 session for 75 min at 75% $\dot{V}O_2$ max heart rate
1 session for 2.25 hr at 65% $\dot{V}O_2$ max heart rate
1 session for 3 hr at 50% $\dot{V}O_2$ max heart rate
1 4-hour bike ride at 60% $\dot{V}O_2$ max heart rate

APPENDIX E

FIN-SWIMMING APPARATUS AND SETUP

DEVELOPMENT OF EXPOSURE GUIDANCE FOR WARM WATER DIVING PHASE 3

Principal Investigator: CDR E. T. LONG, MC, USN

NEDU Protocol Number 01-06